SMALL IRRIGATION PUMPING PLANTS

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THROUGHOUT the United States are many farms, parts or all of which could be irrigated by pumping from either ponds or streams or farm wells. This bulletin is intended to furnish owners or operators of such farms with information that will give them some indication of initial and operating costs and enable them to determine whether soil and water suitable for irrigation are available and what kind of irrigation plant and equipment will be most satisfactory for their purpose. Having examined these factors, a farmer can decide whether irrigation is likely to be profitable on his farm.

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SMALL IRRIGATION PUMPING PLANTS

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WATER SUPPLY FOR IRRIGATION

Before beginning an irrigation system, a farmer should make sure that the supply of water available will be sufficient, particularly during years of drought, since the need for irrigation will be greatest in years of low rainfall. In a few areas where irrigation is undertaken there is an ample supply of water for irrigation throughout the season, but in most places the water supply will limit the irrigation development. In some sections where irrigation water is available from natural streams during the early growing season of a year of normal rainfall but is insufficient at other times, a supplemental supply may be obtained from wells.

QUALITY OF WATER

In some areas either ground or surface waters, or both, carry enough mineral salts in solution to make their use for irrigation unwise or even impossible. No definite figures can be given as to the maximum quantities of dissolved salts that may be present in water used for irrigation. Wherever there is any question about the character of the water, samples should be obtained and tested chemically. Most of the State agricultural experiment stations will test water it is proposed to use for irrigation and will make recommendations as to its use. Sometimes a fee is charged for this service.

In considering the use of water, it should be remembered that the requirements for irrigation are different from those for domestic use. Iron, lime, organic matter, and, especially, animal and human wastes,

[1] Prepared under the direction of W. W. McLaughlin, Chief, Irrigation Division, Soil Conservation Service, and in cooperation with the agricultural experiment stations of Colorado and Oregon.

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make water unfit for household use, but it is satisfactory for irrigation if its use is properly safeguarded.[2] On the other hand, certain types of soft waters useful for domestic purposes may contain enough of the element sodium to make them unsatisfactory for use in irrigation. The idea that well water may be too cold for direct application to the land is not supported by either experiment or experience.

GROUND WATER

On many farms ground water can be developed either as the sole supply for irrigation or as a supplementary supply to be drawn upon when surface waters are not sufficient. Ground water is generally obtained from wells,[3] but occasionally it can be taken from gravel or other open pits.

Very often small gardens and lawns can be irrigated by water from the domestic well. Under ordinary conditions, however, if other areas are to be irrigated, a special irrigation well will have to be dug or drilled. The fact that domestic wells are successful, even when used for watering large numbers of livestock or for other similar purposes, does not prove that sufficient water is available for irrigation. During dry periods it will take about 7,000 gallons a day to irrigate 1 acre of land. That quantity of water would take care of 1,000 head of mixed livestock or a score or more of farmsteads with running water systems. Thus to be satisfactory for irrigation a well must be much better than it has to be to meet the most extravagant requirements of domestic or livestock use. A deep well may stand full of water and still be capable of delivering only a very small stream under continuous pumping.

The capacity of a well depends on its construction and the character of the water-bearing formation into which it is sunk. Unless irrigation well supplies have been obtained in the immediate neighborhood and it is known that the conditions are similar where a new well is wanted, a test well should always be drilled before an irrigation system is planned. Samples of the materials found in the test well should be kept, together with a careful record of the depth and thickness of the strata represented by each sample. From these samples and records a man who has a knowledge of wells and is familiar with local conditions can form a reasonably good estimate of the capacity of a large well and can determine the best type of well construction. If the estimates indicate that an irrigation well can be developed successfully, arrangements can be made for drilling the well and planning the irrigation system. The only way in which the true capacity of a well can be determined is by actual test.

In areas where a great deal of pumping from wells is carried on or may be expected, the question of the ability of the underground basin to supply the required quantity of water continuously over a long period of years becomes important because of danger that the water table will be permanently lowered so far as to make profitable irrigation impossible. It is difficult to estimate in advance how much pumping any particular ground-water basin will stand.

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[2] For a recent discussion of sewage-irrigation practices, and particularly the safeguards public health authorities consider essential in the use of sewage for irrigation, see U. S. Department of Agriculture Technical Bulletin 675, Sewage Irrigation as Practiced in the Western States.

[3] Information on wells for irrigation is given in U. S. Department of Agriculture Circular 546, Putting Down and Developing Wells for Irrigation.

This problem of the capacity of ground-water basins has become so serious in a number of States that laws have been enacted or are under consideration providing for the control of the development of ground water by State officials. In some States a permit must be secured from the State engineer or other appropriate officer before an irrigation well can lawfully be constructed. In most States, however, there is no adequate control of the development of ground water, and before making a large investment in an irrigation system dependent on ground water the prospective irrigator should endeavor to make sure that the ground-water basin has not been or is not likely to be over-developed.

SURFACE WATER

The farmer who proposes to irrigate from surface streams should determine whether he has a right to pump from the stream and whether the stream carries sufficient water for his needs above that needed by other farmers with prior rights. In all the arid and semi-arid States there are laws governing the use of surface water for irrigation. In most of these States surface water cannot be so used legally until an application has been filed with the proper State official and a permit has been issued. Ordinarily such applications are made to the State engineer, and he grants the permits. The State engineer can usually give information about the prior rights on a stream and about the past flow of larger streams; but the farmer himself must determine whether the flow is sufficient for his needs after such prior rights have been supplied. Since the flow of water during dry periods is important to the irrigator, he should make sure, before installing an irrigation system, that there will be sufficient water during times of drought.

Essentially similar legal rules apply to the diversion of water from ponds and reservoirs as from streams. The farmer should make sure that during dry periods there will be enough water in the pond or reservoir for his needs.

Wherever enough good surface water for irrigation can be obtained, its use is to be preferred since irrigation with surface water does not involve the cost and uncertainty of a well. Moreover, equipment suitable for pumping from surface supplies is usually cheaper than that used in wells.

IRRIGABLE LAND

Soil that is deep, fertile, and of high water-holding capacity will give the greatest return for the money and labor expended in irrigation. If water is plentiful it will sometimes be possible to get good returns from poorer lands that are too droughty for satisfactory use without irrigation. This is especially true if such lands are used for truck crops and organic and mineral fertilizers are added in ample quantities. Soils of the gumbo or adobe type are not well suited to irrigation. This is generally true also of alkali soils, but in some places where ample fresh water is available the salts can be leached from these soils and satisfactory crops raised under irrigation.

The relief, or "lay of the land," is more important under irrigation than under rainfall farming. Ideal land for irrigation is smooth and has a uniform fall of 10 to 20 feet to the mile in one direction. Flatter slopes are less desirable because such land must be more carefully leveled before irrigation and it is sometimes more expensive to build

the necessary structures for distribution of the water. On the more steeply sloping lands greater care is required to prevent erosion of the soil. Land sloping less than 3 feet in 100 feet is readily irrigated, and slopes as steep as 15 feet in 100 feet can be irrigated with good results. Steeper lands have been irrigated and can be successfully used for pasture or hay crops, but the application of water to them requires skill and care if destructive erosion is to be prevented. They are not suitable for cultivated or annual crops.

In considering whether land may be irrigated by pumping from any given water supply the question of lift is of great importance. The maximum height to which water can be lifted for profitable irrigation depends on a number of factors, and no exact figure can be given here. As a rough and ready rule, it may be estimated that irrigation should not be undertaken for general farm crops where the total pumping lift is more than 30 feet and the growing season is short or where the lift is more than 50 feet and the growing season is long. Special crops such as deciduous and citrus fruits and garden truck may be irrigated with higher lifts, and small quantities of supplemental water may be provided for special pastures and home gardens at considerably greater heights above the water supply. The special conditions surrounding any proposed irrigation system should be considered before the economic limit of lift is decided upon.

The height to which water may be lifted with profit is almost inversely proportional to the cost of power. Where power can be produced or purchased for 1 cent per horsepower-hour or less the limits suggested above may be increased.

DUTY OF WATER

The term "duty of water" is used to indicate the area of land that may be irrigated with a given stream of water, or, more frequently, the quantity of water required to irrigate a given area of land. The total quantity of water used by crops, including mositure stored in the soil in the spring, effective rainfall, and irrigation water, ranges from about 18 inches in the cooler and more humid areas for the crops that require the least water to 42 inches in the hotter areas for such crops as alfalfa and pasture, which use water extravagantly.

The proportion of this water that must be supplied by irrigation varies from year to year, from region to region, and even from farm to farm, because of differences in crops, soils, and climate. At one extreme are the arid sections of the West, where moisture stored in the soil in the spring months may not exceed 1 or 2 inches and where no effective rainfall may occur during the growing season. Under such conditions practically the entire quantity of water required by the crop must be provided by irrigation. At the other extreme are those areas where the soil is saturated in the spring and a large part of the requirement of the crop is met by rainfall during the growing season. In such areas it will occasionally be found that a single irrigation of 3 to 4 inches, together with the soil moisture and rain, will supply all the moisture needed by the crop.

The figures given above cover only the water used by the crop. In addition there is some waste by evaporation, seepage from ditches, percolation through the soil past plant roots, and surface run-off. With careful management, the proportion of water wasted may be kept to one-quarter of the amount applied, or less. Under careless

use as much as three-quarters or more of the water is sometimes wasted.[4]

Determining the size of stream needed to irrigate a given tract of land is ordinarily a more important problem for the farmer who expects to irrigate by pumping than the total quantity of water required during the season. Even in semihumid sections there are droughts during which crops, having used all of the available soil moisture, must receive their total water supply from irrigation for short or long periods. In such periods a field or farm in the semihumid region will require just as large an irrigation stream as a similar area in an arid section.

The small irrigation pumping plant should be large enough to supply at least 2 inches of water over the irrigated area every week during dry periods. For example, if the plant is to be operated 7 days a week and 24 hours a day, its capacity must be about 5½ gallons per minute for each acre irrigated. If it runs only 12 hours a day and 6 days a week, it must pump about 13 gallons per minute for each acre irrigated. These figures provide a basis for determining whether the water supply is sufficient for the land it is intended to irrigate.

Water must be available at all times during the season and especially during the hottest and driest weather if the crops are shallow-rooted and easily injured by drought. Where the soil is deep and deep-rooted crops such as trees and alfalfa are grown, it is possible to store a considerable quantity of water in the soil. Under such conditions irrigation can be carried on whenever water is available. Under especially favorable conditions very satisfactory crops of some kinds can be produced by a single irrigation in the winter or spring. If crops are grown with one or two irrigations, these applications must be very heavy, and the soil must be deep enough and have a high enough moisture-holding capacity to store a large quantity of water.

PLANT DESIGN

Having determined that land and water are available for irrigation and that irrigation probably can be carried on at a cost less than the benefits reasonably to be expected, the farmer is justified in planning an irrigation system.

LOCATION

The irrigation pumping plant will have to be located where the water is available. If the water is to be pumped from a surface stream, pond, or reservoir, the pump should, if possible, be at the point on the water's edge nearest the high point of the land to be irrigated. If a centrifugal pump is used, it should be set as close as possible to the level of the water. If water is to be pumped from a well, test wells should be drilled before the irrigation well is begun. Sometimes several test holes will have to be sunk before a satisfactory location for the irrigation well is found. The underground formation may determine the location of an irrigation well. In some areas, however, irrigation wells can be placed almost anywhere on a farm, the chance of success being the same at all locations. Under such conditions, it is usually best to drill the well at the high point of the land and thus avoid the need for a long discharge pipe. Occasionally it will be found cheaper to drill the well at a low spot and pipe the water from the well to the high point of the land.

[4] Information on methods of irrigation and of preventing waste is given in Farmers' Bulletin 864, Practical Information for Beginners in Irrigation.

SIZE OF PUMP

The size of the small irrigation pumping plant will be governed by a number of factors. If ground water is being pumped, the capacity of the well to furnish water with a reasonable draw-down is generally the controlling factor. Occasionally wells yield water very rapidly and, with a draw-down of 15 or 20 feet, supply more than enough. In such wells the factors governing the size of the pumping plant are the same as those operating when the pump draws upon a surface stream or pond. Where the source is a pond, reservoir, or surface stream that is larger than is needed for irrigation of the land, the size of plant will depend on the soil, the relief, the crops to be grown, the type of power available, and, to some extent, the farm-labor arrangements.

If a garden or orchard is to be irrigated and the soil is comparatively tight so that water is taken up slowly, a small stream can be used satisfactorily. The water is ordinarily applied by means of furrows; a small stream may be divided between a few furrows and allowed to run 12 or 24 hours, or perhaps even longer, and then diverted to a second small group of furrows. Streams yielding only 20 to 30 gallons per minute can be used in this way without too great a loss of efficiency. If the soil is coarse and takes water readily this system is not satisfactory, and larger streams must be used for shorter periods.

If field crops are to be irrigated, it is generally desirable to have a larger stream of water in order that the irrigation may be carried on quickly. Where the border method of irrigation is used for the irrigation of small grains, pastures, or hay land, a minimum stream of 250 or 300 gallons per minute should be available, and a stream two or three times as large will be found more convenient. On very sandy soil with flat relief, it is difficult to irrigate satisfactorily with streams of less than 1,000 gallons per minute, and twice that quantity is sometimes necessary for effective irrigation.[5]

Except where soil conditions are such that undue losses by deep percolation do not occur when water runs for 12 or 24 hours in one place, it is desirable to use as large a stream of water for irrigation as one man can conveniently handle. If a smaller stream is used, the irrigator spends all his time watching the water, or he leaves it alone while he attends to other duties. In one case he wastes a part of his time, and in the other there is almost sure to be waste of water or incomplete irrigation. One man can handle 450 gallons per minute on well-prepared land and several times as much under especially favorable circumstances.

SIZE OF POWER UNIT

The size of the power unit (gas engine, tractor, electric motor) available on the farm for irrigation pumping may fix the size of the pumping plant. Many electric-power companies have rate schedules that tend to penalize the use of large motors by reason of high service or demand charges based on the size of the motor and high initial steps in the energy rates. Where such rate schedules are in effect, it is desirable to use a pumping plant no larger than is necessary to

[5] Descriptions of methods of irrigation may be found in Farmers' Bulletins 1348, The Corrugation Method of Irrigation, and 1243, The Border Method of Irrigation

do the work and operate it as many hours as possible instead of operating a large pump a short time to reduce labor costs. Occasionally it is most economical to pump water into a small reservoir 24 hours a day and irrigate daily with a large stream for a short time.

The power required to pump water depends on the quantity of water, the total head or pressure against which it is pumped, and the efficiency of the pump. The total head is the sum of (1) the static head, (2) the friction head, and (3) the pressure head. The static head is the difference in elevation between the water surface, while the pump is operating, in the well or other source and the outlet of the discharge pipe. The friction head is the head lost by friction in the suction and discharge pipes and fittings (pp. 24–25). The pressure head is that required to operate sprinklers, if they are used. The pressure in pounds per square inch can be converted to pressure head in feet by multiplying by 2.3. Thus, 30 pounds per square inch is equivalent to a head of 69 feet.

Table 1 shows the horsepower required to pump different quantities of water against total heads ranging from 10 to 100 feet. This table was computed on the assumption that the plant efficiency is 50 percent, and it should be used for preliminary estimates only.

The actual horsepower will depend on the efficiency of the plant, which should be higher than 50 percent if the plant is properly designed. To find the power required at other efficiencies the figure found in the table is multiplied by 50 and the product is divided by the new efficiency figure. For instance, it is required to find the power needed to pump 450 gallons per minute against a total head of 40 feet with an efficiency of 60 percent. The table shows that at 50 percent efficiency 9.09 horsepower would be required. Multiplying 9.09 by 50 and dividing the product by 60 gives a quotient of 7.57, which is the horsepower required at 60 percent efficiency.

TABLE 1.—*Horsepower required to pump different quantities of water against total heads of 10 to 100 feet* [1]

[Efficiency of pumping plant 50 percent of theoretical. Use for preliminary estimates only]

Discharge		Horsepower required for lifts of—									
Gallons per minute	Cubic feet per second	10 feet	20 feet	30 feet	40 feet	50 feet	60 feet	70 feet	80 feet	90 feet	100 feet
25	0.056	0.126	0.253	0.379	0.505	0.631	0.758	0.884	1.01	1.14	1.26
50	.111	.253	.505	.758	1.01	1.26	1.52	1.77	2.02	2.27	2.53
100	.22	.50	1.01	1.52	2.02	2.53	3.03	3.54	4.04	4.55	5.05
150	.33	.76	1.52	2.27	3.03	3.79	4.55	5.30	6.06	6.82	7.58
200	.45	1.01	2.02	3.03	4.04	5.05	6.06	7.07	8.08	9.09	10.10
250	.56	1.26	2.53	3.79	5.05	6.31	7.58	8.84	10.10	11.36	12.63
300	.67	1.52	3.03	4.55	6.06	7.58	9.09	10.61	12.12	13.64	15.15
350	.78	1.77	3.54	5.30	7.07	8.84	10.61	12.37	14.14	15.91	17.68
400	.89	2.02	4.04	6.06	8.08	10.10	12.12	14.14	16.16	18.18	20.20
450	1.00	2.27	4.55	6.82	9.09	11.36	13.64	15.91	18.18	20.45	22.73
500	1.11	2.53	5.05	7.58	10.10	12.63	15.15	17.68	20.20	22.73	25.25
600	1.34	3.03	6.06	9.09	12.12	15.15	18.18	21.21	24.24	27.27	30.30
700	1.56	3.54	7.07	10.61	14.14	17.68	21.21	24.75	28.28	31.82	35.35
800	1.78	4.04	8.08	12.12	16.16	20.20	24.24	28.28	32.32	36.36	40.40
900	2.01	4.55	9.09	13.64	18.18	22.73	27.27	31.82	36.36	40.91	45.45
1,000	2.23	5.05	10.10	15.15	20.20	25.25	30.30	35.35	40.40	45.45	50.51
1,250	2.78	6.31	12.63	18.94	25.25	31.57	37.88	44.19	50.50	56.82	63.13
1,500	3.34	7.58	15.15	22.73	30.30	37.88	45.45	53.03	60.61	68.18	75.76

[1] Adapted from U. S. Department of Agriculture Farmers' Bulletin 1404, Pumping from Wells for Irrigation.

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TYPES AND CHARACTERISTICS OF PUMPS

The pumps most commonly used in lifting water for irrigation are horizontal and vertical centrifugals and deep-well turbines. Each of these types is adapted to particular conditions. Under special conditions, other types such as screw, rotary, plunger, bucket, and air-lift pumps and current wheels are sometimes used. The type best suited to the circumstances depends on the source and quantity of the water to be pumped, the cost of the pump, and the number of hours of operation; and, if a well is used, its diameter, the depth to water, and the draw-down must be considered in selecting the pump. To some extent the personal preference of the purchaser may legitimately influence the choice.

HORIZONTAL CENTRIFUGAL

A horizontal centrifugal pump is the simplest type of irrigation pump (fig. 1). It consists essentially of an impeller rigidly attached

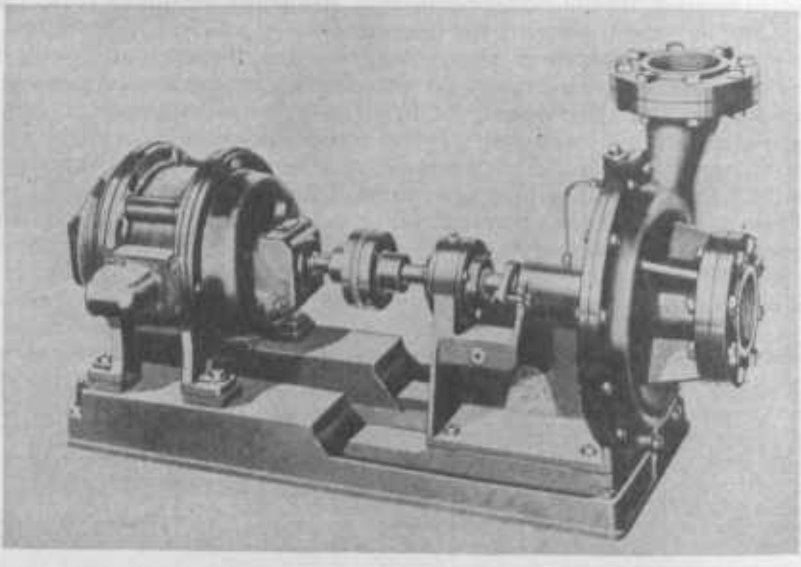

FIGURE 1.—Horizontal centrifugal pump direct-connected to electric motor.

to a horizontal shaft and a case, called the volute, in which it rotates. The impellers may be of the open, semienclosed, or enlosed type shown in figure 2. The open and semienclosed types are used in pumping water containing trash. On account of the leakage between the vanes and the volute these impellers are not so efficient as the enclosed type.

Horizontal centrifugal pumps are of either the single- or the double-suction type. In the single-suction pump there is a partial vacuum on the suction side of the impeller and a positive pressure on the other side. The pressure is equalized in part by drilling holes through the impeller shroud close to the shaft; in addition, thrust bearings, usually of the annular ball type, are provided to counteract any unbalanced thrust. The double-suction pumps are better balanced because the suction acts on both sides of the impeller. As long as the forces are

equal they will balance each other. However, a slight obstruction in the pump destroys this balance, and the thrust bearings are provided to prevent injury to the pump from this cause. The case of double-suction pumps, unlike that of single-suction pumps, is split horizontally. This arrangement makes it possible to inspect the impeller without disturbing the pipe connections simply by taking off the top half of the case. Because the inlet suction is transmitted to the packing glands on the pump shaft they must be kept airtight or the pump will not work satisfactorily. To help keep them tight, water under pressure from the volute is piped to them. If the pumped water is muddy it should be filtered, or clear water should be supplied from a separate source; otherwise the shaft will wear rapidly in the glands, making it impossible to keep the packing tight. Improvements have recently been made in single-suction pumps so that they now compare

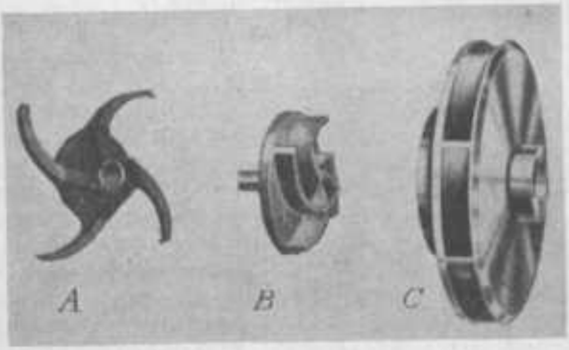

FIGURE 2.—Typical centrifugal pump impellers; *A*, Open impeller; *B*, semi-enclosed impeller; and *C*, closed impeller.

favorably with the more expensive double-suction type in efficiency and dependability.

Horizontal pumps have to be primed; hence some type of primer is required. Foot valves on the suction pipe are not recommended because they increase the suction lift and are frequently not effective because trash catches on the valve seat. A gate valve on the discharge side and a common pitcher pump attached to the volute make a satisfactory priming arrangement.

Horizontal centrifugal pumps are made in sizes to fit every irrigation need, but the 2-, 3-, 4-, 5-, 6-, and 8-inch sizes are the most common. The size refers to the diameter of the discharge opening. A convenient type of small centrifugal pump consists of an electric motor with the pump permanently attached to the motor frame.

VERTICAL CENTRIFUGAL

The vertical centrifugal pump is like the horizontal centrifugal pump except that the shaft is vertical instead of horizontal. The pump itself is submerged in the water, and the shaft extends from it to the ground surface; thus a rigid frame is required to support the shaft bearings and the pump. The most modern pumps of this type have the shaft bearings attached to the discharge pipe, which is made strong enough to support the shaft bearings and the pump without

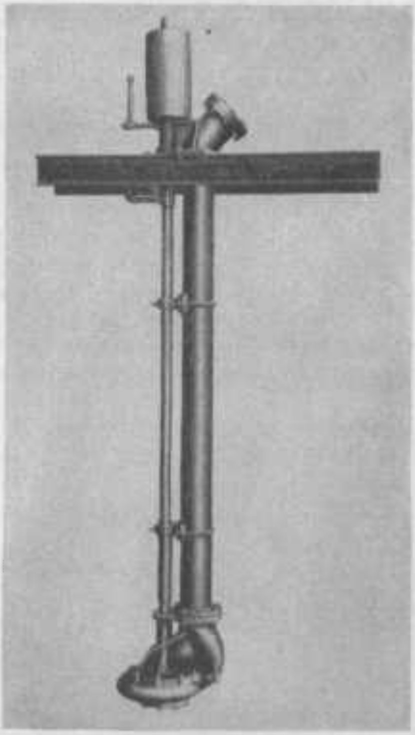

FIGURE 3.—Vertical centrifugal pump with drive shaft attached to the discharge column.

distortion (fig. 3). Some of these pumps have the drive shaft enclosed in a cover pipe to protect it and make possible the effective lubrication of the bearings. A thrust bearing at the top of the shaft takes care of the weight of the shaft and impeller and any unbalanced vertical forces caused by pumping. A watertight packing gland is provided for the shaft where it passes through the case. The most common vertical centrifugal pump is the 6 inch.

DEEP-WELL TURBINE

In the deep-well turbine, the suction pipe, the pump bowl or bowls (referred to as stages), and the discharge pipe are joined together in a straight line. The drive shaft, which may be either oil or water lubricated, is in the center of the discharge column. Water-lubricated pumps are usually built without cover pipes for the drive shaft and have stainless-steel shafts or stainless-steel sleeves at the bearings, which are rubber. An oil-lubricated pump must have a cover pipe for the shaft to keep the water from washing the oil out of the bearings. Neither oil nor water lubrication is entirely satisfactory because of difficulties inherent in the deep-well turbine type of constructon, but well-designed pumps with either type of lubrication have been found to give dependable service. The weight of the shaft and the impeller and the unbalanced thrust of the pump are carried by a thrust bearing in the pump head or motor.

The impellers used in turbine pumps are generally made of cast iron or bronze. For the highest efficiency, cast-iron impellers covered with porcelain are used. The bowls containing the impellers are arranged so that when the water is thrown out of the rotating impeller by centrifugal force it is carried upward through guide vanes that direct the water vertically into the discharge pipe or into the center of the impeller of the next stage (fig. 4). Impellers of the mixed-flow type give the water an upward as well as an outward velocity. Pumps of this type have greater capacity than similar pumps with centrifugal type impellers. Still higher capacities are provided by axial-flow impellers or propellers. Deep-well turbines are made in sizes to fit any well of standard diameter and in capacities suitable for small tracts or large farms. If the number of stages is increased they can be made to pump against any desired head.

CHARACTERISTICS OF CENTRIFUGAL PUMPS

In horizontal and vertical centrifugal pumps and standard deep-well turbines the water is thrown from the center of the rotating impeller by centrifugal force. The partial vacuum thus caused draws more water into the impeller, and this water is in turn thrown out centrifugally. The water as it leaves the impeller has a high velocity, part of which is converted into pressure in the expanding section between the rim of the impeller and the pump case or bowl. This pressure causes the water to flow.

All centrifugal pumps have certain characteristics in common. At any given speed each pump has a rather narrow range of capacity and head within which it will operate at near its highest efficiency. If, at that speed, it is required to operate against a higher head it will deliver less water and require relatively more power. At a still higher head it will cease to deliver any water at all. This is known as the "shut-off" head and may not be much greater than the normal operating head for the pump and speed. At a lower head the pump will deliver more water, but in this case also it will require relatively more power. In other words, the efficiency of a centrifugal pump falls off whenever it is operated at a given speed against either a higher or lower head than that for which it was designed to operate at that speed.

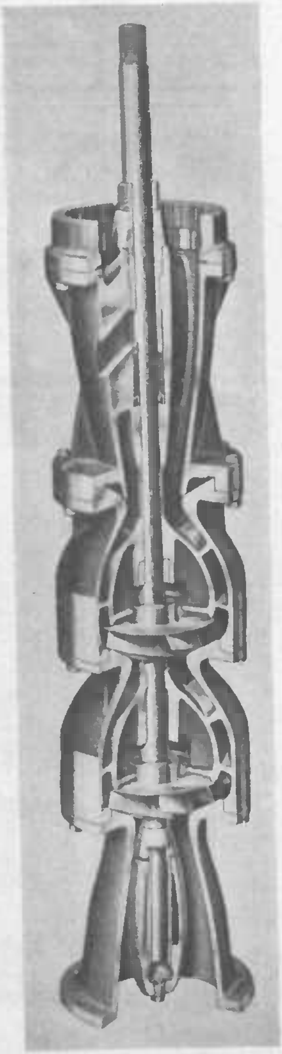

FIGURE 4.—Cutaway view of a two-stage deep-well turbine pumping element.

Changes in the head at which a pump will operate efficiently can be made by changing the operating speed, but at the same time the discharge and the power required will also change. In general, the normal discharge of a centrifugal pump will increase directly as the speed, the head as the square of the speed, and the power as the cube of the speed. Changing the diameter of the impeller has the same effect as changing the speed.

Changing the speed at which the pump in a particular system operates will change the discharge, total head (including pipe friction), and power in the same direction, but the extent of change in each element will depend on the relative values of the static and friction heads. In all cases the power required will increase much more rapidly than the speed.

The limit of suction lift for pumps is determined by the altitude, but for most satisfactory operation the suction should be kept as small as possible. The practical limit of suction for pumps is 22 feet at sea level, 17 feet at 5,000 feet elevation, and 14 feet at 10,000 feet elevation. Pumps will operate when the suction exceeds these limits, but the performance of the pump is usually unsatisfactory.

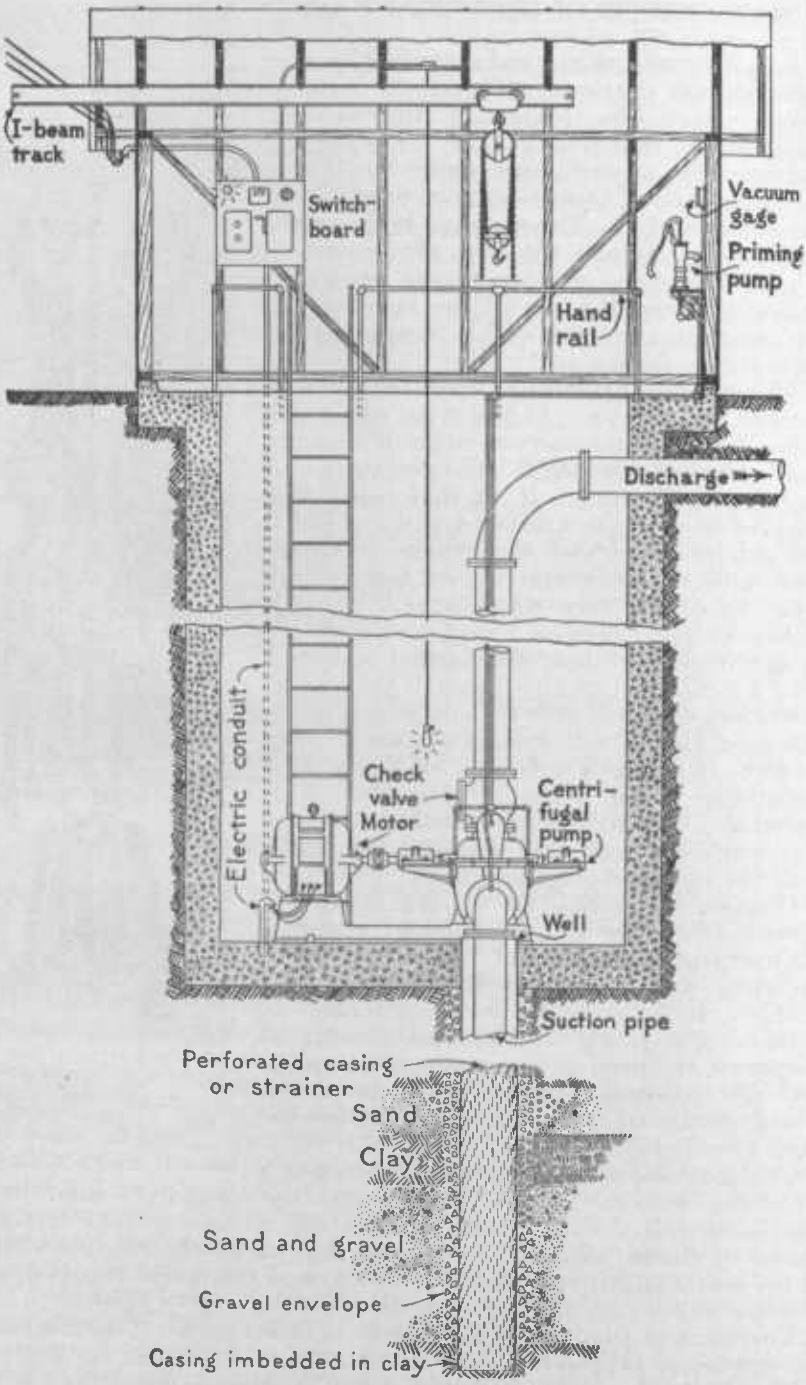

FIGURE 5.—Direct-connected horizontal double-suction centrifugal pump in pit.

Both the capacity and the efficiency of centrifugal pumps decrease as the suction increases.

The efficiency of a pump is the ratio of the useful work done in lifting water from one level to another to the energy expended in doing it. Efficiency is usually expressed as a percentage. There are several kinds of efficiency used in designating the characteristics of pumps, each of which has a different meaning. In comparing the characteristics of pumps from different manufacturers, therefore, all the efficiencies should be on the same basis.

ADAPTABILITY OF THE DIFFERENT TYPES OF PUMPS

HORIZONTAL CENTRIFUGAL

Because of low first cost, light weight, long life, simplicity, ease of operation, and high efficiency, the horizontal centrifugal pump

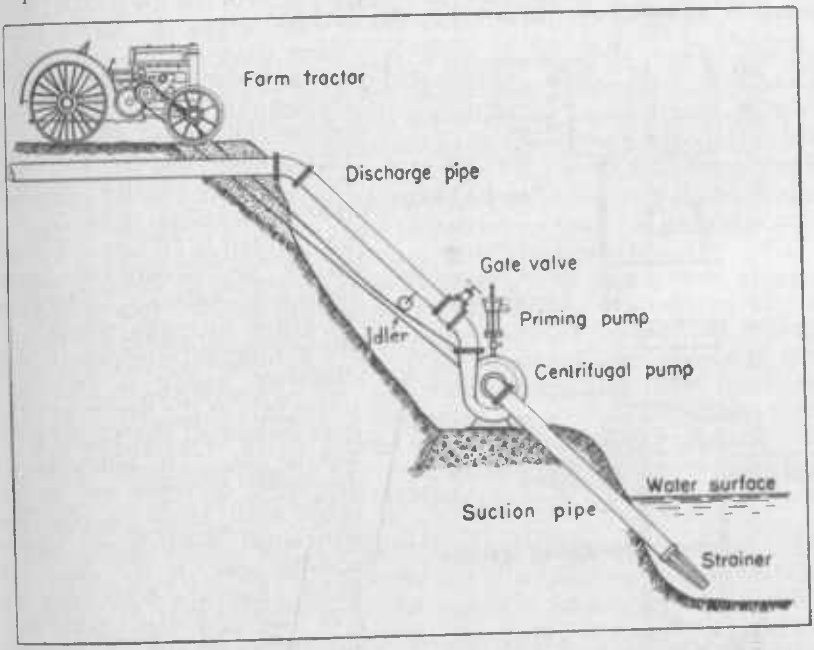

FIGURE 6.—Tractor-driven horizontal centrifugal pump on stream bank.

should be used wherever conditions are favorable. This type is particularly adapted to pumping from wells, reservoirs, canals, and streams where the suction lift does not exceed 22 feet (sea level). Figures 5 and 6 show typical installations of horizontal centrifugal pumps. Where the pumping is from wells, the water level should not be more than 40 feet beneath the surface, since 20 feet below ground is about the practical limit of setting a pump in a pit. The principal objections to this type of pump are that it must be primed, a large pit must be constructed to install the pump near the water surface in a well, and the draw-down in the well is limited to the suction lift. The pump cannot be used where the level of the water supply fluctuates widely unless provision is made for raising and lowering the pump.

VERTICAL CENTRIFUGAL

The vertical centrifugal pump is adapted for use where the water level during pumping is more than 40 feet beneath the surface or where it fluctuates within wide limits, as it does in some wells, streams, and reservoirs. It is not necessary to construct a large pit to accommodate the pump or to prime it. Because the pump is usually submerged, it is not so easily kept in adjustment as the horizontal centrifugal pump. The bearings on the long drive shaft are difficult to keep in alinement and to lubricate properly. For these reasons vertical centrifugals wear out more rapidly than horizontal centrifugals and generally are not so efficient. They are also more expensive and more difficult to repair.

DEEP-WELL TURBINE

Because of its large capacity and compact form the deep-well turbine pump is adapted to insertion in cased wells where the water level is more than 50 feet beneath the ground surface. Successful installations have been made where the water table was 500 feet beneath the surface. Since the bowls are usually submerged the permissible draw-down is not limited to 20 feet. Figure 7 shows an electrically driven deep-well turbine installation. In order to make possible the use of large turbine pumps, wide diameter casing is frequently put down to the depth at which it is estimated the pump bowls will be set. The efficiencies of deep-well turbines are comparable with those of the best horizontal centrifugal pumps, and because of the care with which they are built they will give long and dependable service. They do not require priming. However, they are more expensive than horizontal and vertical centrifugal pumps and are more difficult to inspect and repair.

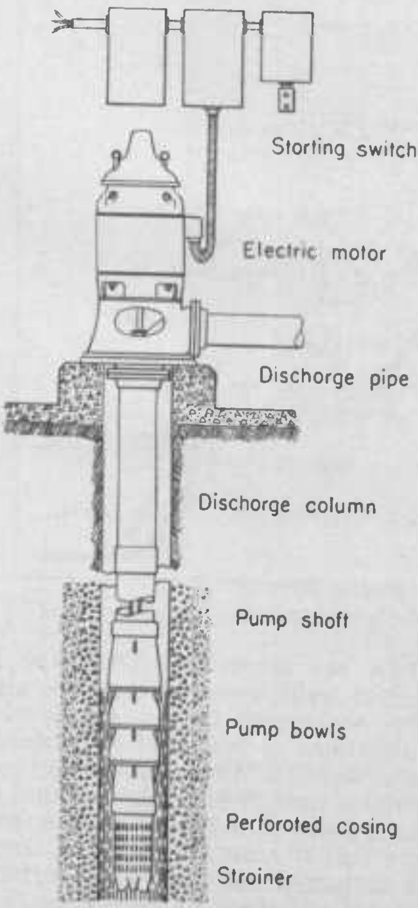

FIGURE 7.—Electrically driven deep-well turbine with line starter.

OTHER TYPES

Air-lift pumps are suitable for pumping from batteries of wells and wells in which the water carries a large quantity of sand. Their efficiency is so low, however, that they are not

recommended for general use. Bucket pumps are efficient, but they have many moving parts that wear out rapidly and are not suitable for installations where the lift is great. They are also expensive. Gear or rotary pumps may be used for pump irrigation, but they also wear out rapidly, and their capacity is small in comparison with their size. It is doubtful whether any of the types named in this paragraph should be used in new irrigation plants.

Plunger pumps were formerly used on all high head or deep-well installations but are being replaced by turbines. Although plunger pumps are highly efficient when new, the plungers wear rapidly and have to be replaced frequently if the efficiency is maintained. They usually do not give as good service as deep-well turbines. Plunger pumps are probably best suited for pumping water where only a small amount is needed, as in irrigating gardens and small orchards. They are also the type best adapted for operation by windmills.

SELECTION OF PUMP

In selecting a pump, the choice will usually be limited to a horizontal or vertical centrifugal or a deep-well turbine. Deep-well turbines are being used in practically all well installations except those in which the water is very close to the surface. In these the horizontal centrifugal pump is the most satisfactory. It is the most satisfactory, also, for pumping from reservoirs, canals, and streams, unless the fluctuation in the water level is too great to permit its use. Where this occurs the vertical centrifugal pump is probably the best type.

The amount of money that can profitably be spent on a pump for irrigation will depend on the value of the crops produced and the number of hours the pump will be operated each season. If it is used for a short period only each year, an expensive unit generally is not economical on account of the high fixed costs which must be charged against the pumped water. For such installations cheaper pumps should be chosen. These pumps are usually lower in efficiency than the more expensive pumps and consequently require more power, but for short periods of operation this disadvantage is more than balanced by the lower first cost.

Great care should be exercised in purchasing used pumps. Most pumps are now built to fit a specific set of conditions; unless the curve showing the characteristics of the pump is available, the purchaser will not be able to find out whether the pump is suited to conditions on his farm. The range of conditions under which each pump will operate at high efficiency is rather limited; outside of this range, even though a pump delivers the required amount of water, it does so at the expenditure of considerably more power than is necessary. Pumps manufactured more than 15 years ago should not be purchased because their efficiency is generally too low for economical operation. New makes of pumps for which extravagant claims are made should also be avoided, as the purchaser of such pumps usually finds that they will not do all that was claimed for them. Manufacturers who do not have proper facilities for testing their pumps are frequently mistaken as to their performance; and since many such companies do not long continue in business, it is difficult to get repair parts when they are needed. Most well-established manufacturers have engineering organizations to which, before making a purchase, the farmer should

submit complete information regarding his plan so that they may select the pump best suited to it.

CARE OF PUMP

Pumps and pipe lines should be drained at the end of the pumping season, especially where freezing occurs. In the spring, oil reservoirs should be cleaned and refilled with the grade of oil recommended for the pump. At that time it is desirable to check the packing in the pump glands and replace it if necessary. If the shaft is badly cut in the packing gland it should be taken out and turned smooth in a lathe. All pipe connections should be checked for leaks and tightened or repacked if necessary. The setting of the impellers in deep-well turbine and vertical centrifugal pumps should be checked from time to time to see whether they are running free. If they are not, the impeller should be reset by adjusting the nut at the top of the drive shaft in the manner described in the directions for operating the pump. Belts should be loosened when not in use but should be kept fairly tight when the pump is driven. Excessive tightness in belts causes undue wear on the bearings and shortens the life of the belt. If the belt has to be run very tight to keep it from slipping, it may be too narrow or the pulley too small. If the pulleys are too close together or if the belt is set to run at too steep an angle, as it may be when the pump is in a pit, it may be difficult to keep the belt from slipping without excessive tightness. The use of longer belts will usually reduce the slippage because it increases the contact of the belt on the pulleys.

CHOICE OF POWER UNIT

The source of power for operating the pumping plant may be either an electric motor or an internal-combustion unit, such as a gasoline, oil-burning spark-ignition, or diesel engine. Steam engines are seldom used. Small plunger pumps are sometimes operated by windmills.

ELECTRIC MOTOR

Where electricity is available at reasonable rates it is the most satisfactory source of power for irrigation pumping. The low cost of electric motors, their reliability, high efficiency, compactness, low cost of upkeep, and the limited attention they need when in operation make them especially desirable for operating pumping plants.

The speed at which each motor operates is fixed by the number of cycles of the current and the number of poles of the motor, but since motors are obtainable in speeds of 870, 1,160, 1,760, and 3,475 revolutions per minute (r. p. m.) for 60-cycle current and in speeds of 725, 965, 1,465, and 2,900 r. p. m. for 50-cycle current, a motor of proper speed for each installation can usually be purchased. Where 60-cycle current is avilable, the 1,760-speed motor is preferred because it is the most common type and usually the cheapest and most efficient. Low-speed motors cost considerably more than those of high speed. In some cases it may be desirable to use a 1,760-speed motor and obtain the proper pumpspeed by the use of a flat belt or a V-belt drive. Vertical motors are made for driving direct-connected deep-well turbines and vertical centrifugals. They have all the advantages of ordinary motors.

The 60-cycle, 220- or 440-volt polyphase, squirrel-cage induction motor is the type most generally used for pumping plants because of its ruggedness and simplicity. No brushes are required. The speed under full load is nearly constant. Late models of these motors, except large sizes, are built for use with push-button starters, which eliminate the need of hand starters or compensators. Squirrel-cage motors will operate with a continuous overload of 10 percent without injury under favorable conditions. The manufacturer should be consulted if there is doubt as to the ability of the motor to handle the load. Single-phase motors are commonly used for loads of less than 5 horsepower and often for 5-horsepower loads.

The motors may be equipped with either sleeve or ball bearings. Vertical motors are made with a hollow shaft through which the pump shaft extends. This arrangement makes it possible to adjust the position of the impeller by means of the nut on the end of the shaft and to attach the lock by which the shaft is disconnected from the motor if the motor is run backwards and the pump-shaft couplings begin to unscrew. The efficiency of these motors is about 90 percent at full load. Standard motor sizes are 1, 1½, 2, 3, 5, 7½, 10, 15, and 20 horsepower.

Protection for the motor should always be provided by a low voltage release and a thermal overload relay, which shut off the motor if the power is cut off or if the motor is overloaded. Weatherproof housings can be supplied on motors that will be exposed to the weather.

INTERNAL-COMBUSTION ENGINE

Where electric power is not available or where it is too expensive, some type of internal-combustion engine is generally used. Internal-combustion engines are classified on the basis of the fuel used: Gasoline engines, including modifications and adjustments thereof to burn natural gas, kerosene, and distillates; and Diesel engines, including spark-ignition oil-burning engines, which burn commercial Diesel fuels as well as lower grade oils such as No. 2 and No. 3 furnace or heating oils.

The selection of the engine most suitable for given load and service conditions depends primarily on the required life and duration of operating periods of the engines. Gasoline engines are substantially lower in initial cost than Diesel engines and have the further advantage that mechanics are almost universally available who can service such engines. Diesel engines have heavier duty performance characteristics and generally give longer service. As the initial cost of a Diesel engine is substantially higher than that of an equivalent gasoline engine, the decision between these two classes depends essentially on the number of working hours per year and the length of life desired of the engine. As a rough indication, the higher initial cost of a Diesel engine may not be justified if the engine is to run less than about 500 hours a year and the life required of the engine is less than about 10 years.

The following suggestions are made to assist in the selection of the most economical and suitable engine for pump service where the load is fairly constant—without peak requirements that greatly exceed the average load.

A primary consideration in the selection of any engine is the nature of the load itself, whether continuous or intermittent. A considerable

margin of power is necessary to permit an engine to handle a load continuously without excessive heating and excessive wear of the engine. On the other hand, a much smaller margin of reserve power in the engine is necessary if the load is intermittent.

An intermittent load may be defined as one in which the engine handles the horsepower requirements for a period not exceeding 1 hour and is only partly loaded for a following period of greater duration than the load period. A continuous load is a constant load, usually having a duration of at least several hours. Irrigation pumping loads are of this type. In order to handle a continuous load the engine must have adequate power output to be able to maintain constant operating temperatures (160° to 180° F.), and must operate at speeds that will not cause rapid deterioration due to wear.

The following discussion primarily concerns the selection of an engine of adequate horsepower for the load imposed. The horsepower rating of an engine determines the speed at which the engine must run to carry the required load. Accordingly, care must be taken by the user to see to it that either the engine speed matches the pump speed so that a direct drive can be employed or that a suitable-sized V-belt or other drive arrangement is used and allowance is made in the engine horsepower rating for the frictional loss of such drive arrangement, usually 5 to 10 percent.

Gasoline Engine

The selection of a new gasoline engine, including such engines equipped for operation on natural gas, kerosene, or distillates, is largely a matter of judgment in matching the engine capacity to the load requirements. In buying a new engine, the manufacturer's rating of the engine in the form of a maximum horsepower curve or published figures of the maximum horsepower of the engine at various speeds are required since this information is the basis for the selection of a suitable engine.

For continuous service the engine should not be rated at more than 75 or 80 percent of the maximum horsepower shown on this curve or in the manufacturer's published figures. It should be noted that these maximum horsepower figures are based on tests made under ideal conditions. Such tests usually have a duration of from 3 to 5 minutes, and the resultant horsepower values are plotted as maximum horsepower output of the engine. Needless to say, so high a horsepower output would not be obtained in the field use of these engines for longer periods.

An engine should run under field-load conditions at a speed substantially below the speed of maximum horsepower shown by manufacturer's tests. The actual speed should be based on the manufacturer's curve or published figures for the required horsepower output. For continuous service it will be roughly 80 percent of the speed of maximum horsepower shown by the manufacturer's test curve.

Use of Natural Gas, Kerosene, or Distillate

In considering the use of natural gas, where such fuel is available at low cost, it should be noted that a gasoline engine properly adjusted will give approximately the same horsepower output when running on natural gas having a heat content of 1,200 British thermal units (B. t. u.) as when running on regular gasoline. As there is a

wide variation in the heat content of natural gas, it is important to determine the quality of the gas before deciding the size of the engine to employ for a given load. The engine horsepower output is closely proportional to the heat value of the gas, and accordingly the engine performance on gasoline may be corrected to determine the engine performance on the natural gas available. When the engine is used on natural gas of a value other than approximately 1,200 B. t. u., change of the engine compression ratio is necessary to obtain the best engine performance and economy.

The principles that apply in the selection and rating of gasoline engines apply also to engines for use with natural gas. When kerosene or No. 1 distillate is used, with proper adjustments, the engine rating should be about 10 percent below the rating when the engine is run on gasoline.

Used Engine

Used engines, such as automobile engines, are frequently available for use in pumping plants. The selection of a used engine of the proper horsepower for the load requirements is more difficult than the selection of a new engine because of the difficulty in determining (1) the working condition of the used engine and (2) the manufacturer's original maximum rating of the engine.

(1) The expense of placing an engine in good operating condition is well justified, and the following suggestions are based on the assumption that the engine has been overhauled and that such parts as piston rings, valves, ignition system, cooling system, fuel system, and bearings are all in good running condition. The most important requirement for this type of service is an adequate cooling system. For example, automobile engines are equipped with cooling systems designed for use on the highway, as distinct from stationary service. An automobile engine in stationary service normally requires a larger cooling system if the horsepower output is to be equivalent to the actual reasonable output of the engine. (See p. 21 for method of cooling.)

(2) The selection of a used automobile engine having adequate horsepower output is difficult if information is not available to the user regarding the manufacturer's rating of the engine, discussed under the heading "Gasoline Engines." The following suggestions may be of assistance.

Low-priced automobiles currently offered have maximum horsepower ratings ranging from about 80 to 85 horsepower. These ratings are based on 3- to 5-minute maximum horsepower output at maximum speed according to test, and therefore they do not represent the horsepower available under continuous duty in the field. Such engines, if in good working condition, should be rated at not over 35 horsepower for continuous service in a stationary installation, and in order to obtain a continuous 35-horsepower output under these conditions, considerable care in providing adequate cooling for the engine is essential. These figures are given as upper limits, and it is recommended that the user employ more conservative values or ratings if high altitude or other unfavorable working conditions exist.

Used automobile engines in what may be called the middle-priced field have maximum ratings ranging from 92 to 105 horsepower. The same principles apply in the selection of these engines, although some

of them obtain their maximum horsepower ratings at lower speeds and accordingly a more liberal continuous rating is possible. Continuous rating may be taken as about 55 percent of the maximum horsepower.

In the high-priced automobiles currently offered the maximum horsepower of the engines ranges from approximately 107 to 140. These engines, in general, are of slower speed and are more conservatively rated as to their maximum horsepower. Therefore, 65 percent of their maximum horsepower may be employed as a continuous rating for the engine, provided adequate cooling is assured and the engine is in good mechanical condition.

Tractor Engine

In using a gasoline tractor engine for continuous pump service it is recommended that the engine be considered as capable of handling a load equal to the rated drawbar horsepower of the tractor. The foregoing is a conservative recommendation, and judgment should be used in deciding whether higher loads may be handled by the tractor engine. This depends, of course, on the cooling facilities provided in addition to the radiator capacity furnished on the engine and on other working conditions.

Diesel Engine

In selecting Diesel engines (fig. 8), as well as oil-burning spark-ignition engines, the principles discussed under gasoline engines apply. However, because of the nature of Diesel engines, more liberal allowances can be made for continuous service. If a new Diesel engine is obtained from the manufacturer, 80 percent of the maximum

FIGURE 8.—Diesel engine direct-connected to deep-well turbine through geared pump head.

horsepower rating of the engine may be considered conservative for pump service.

The principles discussed under "Gasoline Engines" apply also in considering used Diesel engines, whether in tractors or as industrial power units, but a more liberal allowance may be used for the horsepower ratings, to the extent of about 10 percent. In other words, the drawbar horsepower may be exceeded by about 10 percent for continuous service.

Care and Operation of Engine

In order to obtain the best efficiency, internal combustion engines must be operated at the proper temperature. This requires that the cooling system be kept in the best working order. If a radiator is used, it should be kept clean by the use of water free of dissolved salts because they would be deposited in the radiator through the action of the heat and evaporation. Frequent draining of the radiator should be avoided because any temporary hardness in the water will form a deposit in the radiator as soon as the water is heated; it is better to retain the water that has already lost its temporary hardness by heating. Some engines are operated without radiators by forcing the water from the engine through a cooling coil placed in the water being pumped. The cooling system is filled with pure water, which is circulated by the water pump on the engine. The temperature is controlled by a valve that regulates the amount of water passing through the cooling coils. An open tank with a reserve supply of pure water should be placed in the cooling circuit to take care of the evaporation loss and volume changes due to heating and cooling and protect the engine if the irrigation pump should stop.

Internal-combustion engines should be kept in proper adjustment. An excess of fuel injected into the cylinders of a Diesel engine causes carbon to build up rapidly, and since the compression space is small a slight carbon deposit will cause a large increase of pressure in the cylinder. It also increases fuel consumption. Too rich a mixture increases fuel consumption of gasoline engines, and it may cause serious oil dilution. Proper timing of the ignition or fuel-injection systems is very important. If the timing is wrong, maximum power will not be developed, and excessive knocking and heating may occur.

Careful attention should be given also to the lubrication of the engine. The recommendation of the manufacturer should be followed as to the grade of oil to use. The use of an oil filter and an air cleaner protects the engine and prolongs its life. A substantial shelter protects the engine from the weather and, if locked, prevents tampering with the equipment.

All internal-combustion engines are affected by the rarefaction of the air due to altitude, and at more than 3,000 feet above sea level the horsepower of electric ignition engines should be reduced 3 percent for each 1,000-foot rise. Diesel engines also are affected by rarefaction of the air but probably not to so great an extent as other engines. A reduction of 1 percent in horsepower should also be made for each 10° rise in air temperature above 60°.

WINDMILL

Wherever the quantity of water to be pumped is small (50 gallons per minute or less) and the total lift does not exceed 50 feet, the

possibility of using windmills should be investigated. The power produced by windmills is generally small. It increases rapidly with the size of the mill and with the velocity of the wind; in fact, doubling either of these increases the power nearly four times. A 12-foot mill in a 30-mile wind develops approximately 16 times as much power as a 6-foot mill in a 15-mile wind. To develop this power the mill must operate at the proper speed, that is, approximately one-half the no-load speed. This requirement is one of the chief disadvantages of windmills, because if the windmill is equipped with a pump cylinder that gives the proper load for a 15-mile wind, the mill will run too fast in a 30-mile wind to develop its maximum power and too slow in a wind of less velocity. It probably will not run at all if the velocity drops as much as one-half. Since the gear ratio of the mill and the size of the pump cylinder are fixed, it is important to design the plant to operate most efficiently at the wind velocity most prevalent in the area. Wind-velocity measurements are made at all United States Weather Bureau stations, and information as to the most prevalent wind velocity should be obtained from the nearest station where conditions are comparable. With this information and knowing the head against which it will be necessary to pump, the windmill manufacturer will be able to estimate the size of the mill and pump cylinder that should be used and the quantity of water it will be possible to pump.

It is usually unsatisfactory to try to irrigate with the small quantity of water available from windmills. Better results will be obtained if the windmill pumps into a small reservoir from which the water may be drawn at a high rate when needed.[6]

TYPES OF DRIVES

The greatest efficiency is obtained when the engine or motor is direct-connected to the pump. This is feasible only when the pump speed is the same as the engine or motor speed. When the speeds differ, it is necessary to use some type of belt or gear drive. Either a flat belt or a V belt may be used, and by choosing the proper combination of pulleys any desired speed may be obtained. In order to obtain the best results from flat belts the proper width and thickness of belt should be chosen (table 2), and sufficient distance should be provided between the pulley centers so that it is not necessary to have the belt excessively tight to keep it from slipping. Pulleys with small diameters should not be used.

V-belt drives are more efficient than flat-belt drives and operate satisfactorily when the distance between pulley centers is small (fig. 9). The use of V belts permits installing the motor or engine beside the pump in a pit. V belts with a quarter turn may also be used in driving a vertical pump, but they should be slightly longer than belts used normally. Horizontal motors with ball bearings may be set vertically and used to drive vertical pumps by means of V belts. The recommendations of the manufacturer should be followed in choosing the proper V-belt size, number of belts, and pulley diameters. An efficiency of from 90 to 95 percent may be expected from a well-designed V-belt drive.

[6] Information in regard to building farm reservoirs is given in Farmers' Bulletin 1703, Reservoirs for Farm Use.

TABLE 2.—*Maximum horsepower ratings per inch of width*[1] *of good quality rubber belting with 180° arc of contact*[2]

Number of plies	Smaller pulley diameter (inches)	Horsepower ratings when speed of pulley is—							
		250 revolutions per minute	500 revolutions per minute	1,000 revolutions per minute	1,500 revolutions per minute	2,000 revolutions per minute	2,500 revolutions per minute	3,000 revolutions per minute	3,500 revolutions per minute
3	5		0.6	1.2	1.7	2.1	2.5	2.8	3.0
	6		.9	1.7	2.4	2.9	3.3	3.6	3.7
	8		1.5	2.7	3.6	4.3	4.8	4.9	
4	6		1.0	1.8	2.5	3.1	3.5	3.7	3.9
	8		1.6	3.0	4.0	4.7	5.1	5.1	
	10	1.2	2.3	4.1	5.3	6.0	6.2		
5	10	1.4	2.5	4.3	5.5	6.2	6.3		
	12	1.8	3.3	5.6	7.0	7.6			
	14	2.2	4.0	6.7	8.3				
6	12	2.0	3.5	5.8	7.2	7.5			
	14	2.6	4.5	7.1	8.6				
	16	3.0	5.3	8.3	9.8				

[1] To find belt width, divide required horsepower by quantity indicated in the table.
[2] Adapted from Goodyear Handbook of Belting, ed. 2.

Geared heads are used successfully in transmitting power from engines to vertical-centrifugal and deep-well turbine pumps (fig. 8). A short shaft with a universal joint on each end connects the engine

FIGURE 9.—V-belt drive through geared head on deep-well turbine pump.

shaft with the geared head, permitting slight settlement of the engine or pump. For the ordinary sizes the prices are not greatly different from the combined price of the belted pump head and V-belt drive. The efficiency of the geared head drive is about 95 percent or more.

PIPING

Well casing and standard pipe with welded, screw, or flange joints are best adapted for all piping on the suction side of the pump. If welded joints are used a flange coupling should be provided at the pump. Light-weight welded or riveted pipes do not make satisfactory

suction pipes because they rust through quickly. It is also more difficult to make air-tight joints in light-weight pipe.

Practically all types of pipes and joints are utilized for the discharge. Concrete pipe and sewer tile may be used in low-pressure lines where there is no danger from water hammer or other shocks. Under most conditions these pipes are the most resistant of all to deterioration, but they are not so strong as other pipes, and since they are liable to crack they may leak badly. Used well casing or standard pipe is excellent for discharge pipe. If not too old, either will give long service because the metal is thick enough to withstand corrosion much longer than light-weight welded or riveted pipe. The sections of pipe may be connected by ordinary screw couplings or flanges, or they may be welded together.

Light-weight pipe, both black and galvanized, with either welded or riveted seams is used most frequently for the discharge. The sections of pipe are usually held together by slip joints or patented couplings, and if the pipe is under considerable pressure the slip joints are fastened together by wire ties or bolts attached to lugs on each side of the joint. Where small bends occur in the pipe line, sleeve-type couplings such as those shown in figure 10 are installed, as they are more flexible than slip joints, and they also act as expansion joints. Flanged couplings or unions are used wherever provision must be made for disconnecting the pipe, as, for example, where the pipe is joined to the pump.

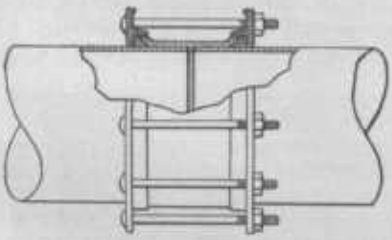

FIGURE 10.—Sleeve coupling for all types of steel pipe.

Under most conditions galvanizing is the best method of protecting steel pipe against corrosion. Since this process is expensive, a more common practice is to coat the pipe with a tough asphaltic or coal-gas tar paint. This can best be done by holding the pipe in a heated tank containing the paint until the pipe also becomes heated. Additional protection is obtained on the outside of the pipe by covering it with specially treated paper or fabric, which is wound around the pipe outside of the paint covering.

The proper diameter of pipe for a pumping plant depends on many factors, most important of which is the head lost in friction. The friction loss in steel pipe, per 100 feet, when discharging different quantities is given in table 3. Friction losses will be 10 to 15 percent greater in concrete pipes. The table discloses that the friction loss decreases rapidly until it is about 0.5 foot per 100 feet; after that the decline is at a much slower rate. The heavy line in the table indicates approximately where the change occurs. The proper size of pipe to use will be somewhere at the right of the line unless the pipe line is short, in which case the sizes immediately at the left of the line will be satisfactory. If a long pipe line is required, an engineer should investigate the problem in order to determine the most economical size.

Pipe lines should always be made as short as possible, and the fewer the bends, pipe fittings, and sudden changes in the pipe diameter in the line the less resistance there will be to the flow of water. This

TABLE 3.—*Loss of head due to friction, per hundred feet of new, thin riveted steel pipe* [1]

Discharge		Loss of head per 100 feet of pipe having inside diameter of—								
Gallons per minute	Cubic feet per second	3 inches	4 inches	5 inches	6 inches	8 inches	10 inches	12 inches	14 inches	16 inches
		Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
25	0.056	0.20	0.05							
50	.111	.74	.18	0.06						
75	.167	1.60	.39	.13						
100	.223	2.76	.68	.22	0.09					
150	.334	5.96	1.46	.49	.20					
200	.446	10.31	2.53	.84	.35	0.08				
300	.668		5.46	1.82	.74	.18	0.06			
400	.891		9.42	3.15	1.29	.31	.10			
500	1.114			4.81	1.97	.48	.16	0.07		
600	1.337			6.80	2.79	.68	.23	.09		
700	1.560			9.13	3.74	.91	.31	.13	0.06	
800	1.783				4.81	1.18	.39	.16	.08	
900	2.005				6.01	1.47	.50	.20	.10	0.05
1,000	2.228				7.35	1.80	.60	.25	.12	.06
1,250	2.785					2.75	.92	.38	.18	.09
1,500	3.342					3.88	1.30	.53	.25	.13

[1] Based on Scobey formula when K_s = 0.34. See p. 12 of U. S. Department of Agriculture Technical Bulletin 150, Flow of Water in Riveted Steel and Analogous Pipes.

matter should be given special consideration in laying out the suction pipe because both the capacity and the efficiency of the pump decrease as the suction increases. The suction pipe is usually made larger than the pump inlet for this reason. Long-sweep elbows are better than standard elbows. If a gate valve is required for priming the pump it should be placed on the discharge, preferably near the pump outlet. (See fig. 6.) This arrangement makes it possible to use a smaller valve, since the discharge pipe is usually larger than the pump outlet. The increase in loss of head through the smaller valve usually is not enough to warrant buying the larger valve. The outlet of the discharge pipe should be made as low as possible. It is not unusual to see discharge pipes sticking up 3 to 4 feet or more above the outlet ditch. Such an arrangement increases the head against which the pump must operate by just that much and increases the cost of power for pumping by a proportionate amount.

COSTS

The cost of a small irrigation pumping plant depends on the size of the plant, the type of equipment, and the local conditions. For these reasons definite figures for total cost cannot be given. The approximate cost of the various items required may be used, however, in making a preliminary estimate of the cost of a plant. All prices in this report are for the year 1939 and are based on quotations for the Rocky Mountain region. Prices on the Pacific coast are slightly lower.

PUMPS

The capacity, horsepower required per foot of lift, and cost of the different sizes of horizontal centrifugal pumps that are commonly used are given in table 4. The prices are for single-suction ball-bearing pumps of substantial construction and good efficiency and are f. o. b. factory. These pumps have semienclosed cast-iron im-

pellers and stainless-steel shafts. The prices of pumps with bases for direct-connected motors do not include the motor. Prices of motors are given in table 5.

The factory price of a 6-inch vertical centrifugal pump with belted head and vertical shaft in cover pipe attached to discharge column is approximately $400. This price is for a 40-foot setting and includes the 40 feet of discharge column. For greater or less depths $5 per foot should be added to or subtracted from the price. This pump has a capacity of 400 to 1,200 gallons per minute, but it is most efficient for discharges between 600 and 900 gallons per minute with heads of 15 to 40 feet.

Deep-well turbine pumps are usually purchased installed in the well because special equipment as well as experience is required in doing the work. Table 6 gives the installed prices of motor-driven deep-well turbines for lifts of 30, 50, and 80 feet and for discharges of 225, 450, and 900 gallons per minute. These prices include in addition to the motor, starter, and wiring, 10 feet of suction pipe and a strainer. The prices are the same whether the pump is oil- or water-lubricated. The prices of pumps with belted or geared heads are less than those shown in the table. Pumps with geared heads can be operated at higher speeds than belt-driven pumps; consequently a smaller and cheaper pump can be chosen when a geared head is used.

TABLE 4.—*Cost of horizontal, single-suction, ball-bearing centrifugal pumps of different sizes, typical capacities, and required operative horsepower, 1939* [1]

Centrifugal pump size (inches)	Discharge per minute	Theoretical horsepower per foot of lift	Pump efficiency	Actual horsepower per foot of lift [2]	Pump with pulley		Pump with base [3]	
					Cost	Weight	Cost	Weight
	Gallons		*Percent*			*Pounds*		*Pounds*
2	200	0.051	40–60	0.12	$60	125	$100	185
3	300	.076	65–75	.12	80	210	130	285
4	500	.126	65–75	.19	100	225	150	300
5	700	.177	65–75	.27	120	350	180	450
6	1,000	.253	70–80	.36	140	375	200	475
8	1,500	.379	70–80	.54	240	675	310	1,150

[1] The prices are f. o. b. factory.
[2] Efficiencies taken as the lower values in the preceding column.
[3] Includes flexible coupling for direct-connected motor, but does not include motor.

TABLE 5.—*Delivered prices of 3-phase 60-cycle, 220 or 440 volt, squirrel-cage induction motors, complete with base, pulley, and line starter or compensator, 1939*

Motor size (horsepower)	1,760 revolutions per minute			1,160 revolutions per minute			870 revolutions per minute		
	Weight	Pulley size [1]	Price	Weight	Pulley size [1]	Price	Weight	Pulley size [1]	Price
	Pounds	*Inches*		*Pounds*	*Inches*		*Pounds*	*Inches*	
2 [2]	190	4 x 3	$72	270	4½ x 4	$128	---	---	---
3 [2]	190	4 x 3	90	285	4½ x 4	153	---	---	---
5 [2]	270	4½ x 4	128	455	5 x 4	184	---	---	---
7½	320	5 x 4	134	425	6 x 5	161	505	8 x 6	$191
10	425	6 x 5	161	505	8 x 6	184	670	9 x 7	226
15	485	8 x 6	184	505	9 x 7	226	825	10 x 7	268
20	655	9 x 7	230	840	10 x 7	286	925	10 x 7	326
25	675	9 x 7	255	925	10 x 7	326	1,150	11 x 9	368
30	925	10 x 7	326	1,150	11 x 9	368	1,165	11 x 9	442
40 [3]	1,520	11 x 9	516	1,635	11 x 9	575	1,840	12 x 10	633

[1] First figure is pulley diameter; second figure is belt width.
[2] Single phase, 110 to 220 volts.
[3] Equipped with compensator, others with line starters.

TABLE 6.—*Installed prices of oil- or water-lubricated direct-connected motor-driven deep-well turbine pumps for motor speeds of 1,760 revolutions per minute, 1939*

Pump size (gallons per minute)	Setting	Bowl diameter	Stages	Column diameter	Motor size	Price installed [1]
	Feet	*Inches*	*Number*	*Inches*	*Horsepower*	
225	30	7½	1	5	3	$475
	50	7½	2	5	5	600
	80	7½	3	5	7½	760
450	30	9½	1	6	5	560
	50	9½	2	6	10	785
	80	9½	2	6	15	935
900	30	9½	2	8	10	755
	50	12	1	8	15	880
	80	12	2	8	25	1,200

[1] The price includes pump and motor, 10 feet of suction column strainer, starter, and cost of wiring between transformers and motor.

Windmill-driven plunger pumps for shallow wells capable of discharging 10 to 25 gallons per minute require a large cylinder and a special pump head. The factory prices of these cylinders are given in table 7. The special pump heads may be purchased, but they are usually made by placing a T in the well pipe at the ground surface. A short length of pipe in the side opening in the T provides a spout, and a similar one in the top keeps the water from splashing out. In addition to the pump head and cylinder, a 3- or 4-inch drop pipe is required, also a pump rod. The prices of drop pipe, which is made of either standard pipe or well casing, are given in table 8. The pump rod may be made of ½-inch pipe or 2′′ by 2′′ wooden rods. The latter are to be preferred because they are more resilient than steel rods.

POWER UNITS

The delivered prices of the different sizes of horizontal squirrel-cage induction motors for different speeds are given in table 5. These prices include line starters or compensators, pulleys, and bases. These motors are equipped with sleeve bearings. An additional charge is made for ball bearings.

Single-cylinder electric ignition gasoline engines up to 20 horsepower can be purchased for $25 to $30 per horsepower. These prices include the cost of a clutch pulley. Prices of multiple-cylinder industrial power units are similar except for the smaller sizes, which are considerably higher. None of these prices include the engine base. Equipment for burning natural gas, which includes regulating valves and special high-pressure cylinder heads or pistons, will cost about $25 to $35 per engine.

Used automobile engines can be bought for $25 to $100, depending on their condition. A suitable power take-off has to be provided before the engine can be used to drive a pump. This can generally be done at a nominal cost.

The approximate delivered prices of high-speed Diesel power units are given in table 9. These prices include base, clutch, special shaft, fuel tank, radiator and fan-cooling equipment, starter, and supervision of the installation of the engine. If some of the parts are not required, a reduction in price is made.

Single-cylinder high-speed Diesel engines of 5 and 10 horsepower are considerably more expensive per horsepower.

TABLE 7.—*Factory prices of different sizes of cylinders and of back-geared steel windmills, 1939, and manufacturer's recommendations as to cylinder size and capacity*

Mill diameter (feet)	Length of cylinder	Length of stroke	For a head of 25 feet			For a head of 50 feet			Windmill with 40-foot tower	
			Cylinder diameter	Price of cylinder	Discharge [1]	Cylinder diameter	Price of cylinder	Discharge [1]	Weight	Price
	Inches	*Inches*	*Inches*		*Gallons per minute*	*Inches*		*Gallons per minute*	*Pounds*	
6	12	5⅝	3	$5.50	4	2	$4.50	3	900	$75
8	12	5⅝	3¾	8.50	6	2¼	5.00	4	1,100	85
10	14	6¼	4½	19.50	10	2¾	6.00	5	1,200	100
12	16	8	5½	35.00	16	3¼	8.00	8	2,100	165
14	18	10½	6½	37.50	25	3¾	10.50	13	2,900	275
16	20	12	7½		30	4½	22.00	18	3,400	360

[1] Quantity of water pumped is for a 15-mile wind; for a 30-mile wind the quantity will be approximately 4 times as great if the stroke of the plunger is increased so that the mill is loaded to the proper capacity. If the wind drops below 15 miles per hour part of the time the quantity pumped will be considerably less than the amount indicated in the table.

TABLE 8.—*Prices of different kinds of pipe and gate and check valves, 1939*

Inside diameter (inches)	Price per foot of—					
	12-gage black	12-gage galvanized	Standard pipe (black)	Well casing (black)	Gate valves	Check valves
2			$0.19		$4.50	$3.00
3			.40	$0.35	7.50	8.00
4	[1] $0.40	[1] $0.45	.60	.50	15.75	13.50
5	[2] .59	[2] .63	.82	.66	22.75	20.00
6	.91	1.01	1.07	.89	26.75	25.00
8	1.06	1.16	1.47	1.25	45.00	46.50
10	1.25	1.37	1.91	1.92	74.50	73.50
12	1.47	1.61	2.74	2.65	103.00	106.00

[1] 16-gage.
[2] 14-gage.

The factory prices of the different sizes of pump cylinders and windmills and towers are given in table 7. The recommendations of the manufacturer in regard to the stroke, size of cylinder, and capacity when operating in a 15-mile wind are also given.

BELTS

A good grade of four-ply canvas belting suitable for most pump drives can be purchased at 30 cents a foot for 4-inch belting, 35 cents for 5-inch, 40 cents for 6-inch, and 50 cents for 8-inch. The price of rubber belting is about 20 percent higher.

PIPES

The warehouse prices of gate and check valves and of different kinds and sizes of pipes are given in table 8.

Used standard pipe and well casing satisfactory for irrigation pumping plants can sometimes be purchased at a considerable saving. Gate and check valves that are no longer in perfect condition but are satisfactory for pump discharge lines can also usually be purchased at reduced prices.

TABLE 9.—*Delivered prices of high-speed Diesel industrial power units, 1939*

Horsepower	Weight	Cylinders	Speed	Price
	Pounds	*Number*	*Revolutions per minute*	
25	3,100	4	1,500	$1,220
35	3,800	4	1,400	1,605
45	5,700	3	850	2,120
50	6,300	4	850	2,255
60	6,300	4	850	2,470

ANNUAL COST

The annual cost of a pumping plant is made up of the fixed charges and the operating cost. The fixed charges consist of the interest on the investment, the taxes on the equipment, and the depreciation. These items are practically independent of the extent to which the equipment is used; consequently if the plant is operated but a short time each year the fixed charges per acre-foot of water pumped will be very high. In computing the interest on the investment the entire cost of the plant should be considered, and the amount charged should be based on the current rate of interest. Taxes, unless the plant is within the city limits, probably will not exceed 2 percent of the cost of the plant. The depreciation depends on the life of the plant. If it is estimated that the life will be 15 years, one-fifteenth of the cost of the plant should be added each year to the fixed charges. The entire annual fixed charges will amount to 10 to 15 percent of the cost of the plant.

The annual cost of operation consists of the cost of fuel or electricity, lubricating oil, repairs, and attendance. Gasoline engines will burn about one-eighth gallon per horsepower-hour when operated at their rated capacity. Gasoline for power units can be purchased for 10 to 15 cents per gallon, since in most States it is exempt from tax. Diesel engines require about seven-tenths as much fuel per horsepower-hour as gasoline engines, and the price of the fuel is 3 to 8 cents per gallon, depending on the locality. The fuel cost per horsepower-hour for a Diesel engine will therefore be about one-third of that for a gasoline engine.

Electricity is sold by the kilowatt-hour, which is the equivalent of 1.34 horsepower-hours. The price depends on the size of the motor, the amount of power consumed, and the rate schedule. Most rate schedules contain a demand charge based on the horsepower of the motor that must be paid whether the pump is used or not. In addition to the demand charge there is a charge for the power used. This charge is on a sliding scale in which the cost per kilowatt-hour decreases as the amount of power consumed increases, but the rate of decrease is not so rapid for large motors as for small motors. For example, under a common form of rate schedule a 5-horsepower motor would have to consume 4,000 kilowatt-hours of energy before reaching the lowest rate, whereas a 10-horsepower motor would have to consume 8,000 kilowatt-hours before reaching the same rate. This is the reason why the smallest motor that will pump the necessary amount of water should be chosen. Under favorable conditions the cost of electrical energy may be as low as 1 cent per kilowatt-hour or even less; generally, however, it is somewhere between 1 and 3 cents per kilowatt-hour.

The cost of lubricating oil for an electrically driven pumping plant is negligible, but for a plant driven by a Diesel or gasoline engine it is an important item in the cost.

The cost of attendance, likewise, is much higher for engine-driven plants than for electric plants. About 1 hour per day will be sufficient for an electric plant and from 2 to 4 hours for engine-driven plants.

Repair costs chargeable to ordinary wear are higher for engines than for motors. Careful attention to lubrication and to protection of the equipment from the weather, and particularly from dust, will result in a considerable saving in repairs. Repairs necessitated by accidents or breakage cannot be foreseen, but in estimating the cost of operation some allowance should be made for such accidents. From $25 to $50 will probably cover the total annual cost of repairs for electric plants and from $100 to $150 for engine-driven plants.

A study of the cost of operation of a group of pumping plants in Colorado during 1929 and 1930 [7] showed that the average total annual cost of operation, including fixed charges, was 15 cents per acre-foot per foot of lift for motor-driven plants and 20 cents for engine-driven plants. A study made of motor-driven plants in Central California in 1923 [8] showed costs per acre-foot per foot of lift ranging from 5 to 60 cents.

Since these studies were made, the efficiency of pumps has been considerably improved. There has also been a reduction in the cost of electricity and an improvement in engines. It is believed that under present conditions a well-designed plant operated so as to get the most economical service from the equipment should pump water at a total cost not to exceed 5 or 6 cents per acre-foot for each foot of lift. Complete records on two well-designed plants in Colorado,[9] one motor-driven and one diesel-driven, show that water can be pumped at an annual cost of less than 5 cents per acre-foot per foot of lift.

[7] Colorado Experiment Station Bulletin 387, Cost of Pumping for Irrigation in Colorado.
[8] California Department of Public Works, Bulletin 8, Cost of Water to Irrigators in California.
[9] Colorado Experiment Station Bulletin 433, Equipping a Small Irrigation Pumping Plant.

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